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SECTION 24

GROUNDING SYSTEMS

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24.1 INTRODUCTION

In the last few decades, much has been ascertained about the interaction between the grounding electrode and the earth, which is a three-dimensional electrical circuit. Ultimately, it is the soil resistivity (and special variations thereof) that determines system design and performance. New technology has significantly reduced the resistance between grounding electrodes and the surrounding soil, which is a determining factor in the performance of small electrodes. There are a number of different grounding electrodes in use today. They are the standard driven rod, advanced driven rod, grounding plate, Ufer (concrete encased electrode), water pipes, and the electrolytic electrode.

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The National Electric Code (NEC) divides grounding into two distinct areas: *equipment grounding* and *system grounding*. Equipment grounding is the process of connecting above-ground equipment to the earth. In other words, how to properly bond wires to equipment, routing them through conduits, circuit-breaker boxes, etc. System grounding is the process of intentionally making an electrical connection to the earth itself. This is the actual connection of metal to soil, and the minimum standards by which this connection is made. This process is often referred to as *earthing*.

The goal for this chapter is to provide a basic knowledge of system grounding and earthing in an easy-to-read and understandable manner. Above-ground wiring issues, except where needed is not discussed. The topics covered are system grounding, the benefits and features of the available grounding electrodes, and the ground potential rise (GPR) hazards of high current discharges. We also introduce the principles of proper soil testing, resistance-to-ground (RTG) testing, and meter selection.

Both equipment grounding and system grounding are becoming more essential as technology rapidly advances. Many of the latest and most advanced systems have stringent grounding requirements. Understanding the available electrical data through proper ground testing enables the electrical engineer to manage grounding systems that will meet specified grounding criteria.

Our goal is to provide the basic knowledge needed to understand and make the right choices when it comes to electrical grounding. Remember, “To protect what’s above the ground you need to know what’s in the ground.”

24.2 SPHERE OF INFLUENCE

An important concept as to how efficiently grounding electrodes discharge electrons into the earth is called “the zone of influence,” which is sometimes referred to as “the sphere of influence.” The zone of influence (Fig. 24-1) is the volume of soil throughout which the electrical potential rises to more than a small percentage of the potential rise of the ground electrode, when that electrode discharges current into the soil. The greater the volume compared with the volume of the electrode, the more efficient the electrode. Elongated electrodes, such as ground rods, are the most efficient. The surface area of the electrode determines the ampacity of the device, but does not affect “the zone of influence.” The greater the surface area of the electrode, the greater the contact with the soil and more electrical energy can be discharged per unit of time.

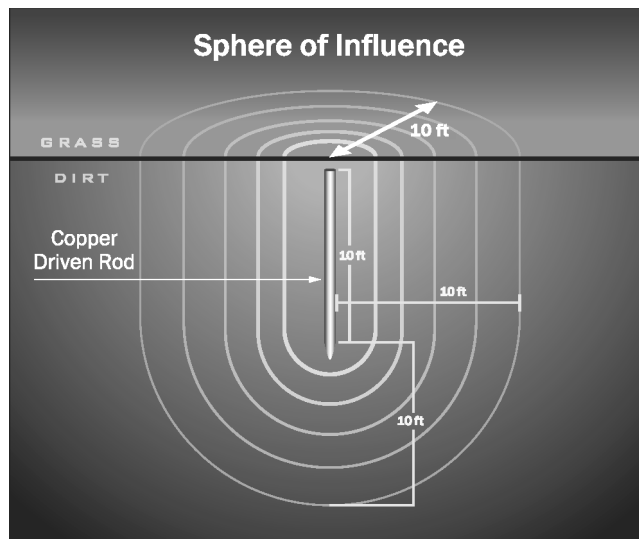


FIGURE 24-1 Sphere of influence of an earth electrode.

The formula for calculating the volume of soil is

$$V = 5\pi L^3/3 \quad (24-1)$$

where V = the volume of soil in the sphere of influence and L = the length or depth of the electrode.

A simpler version of the equation is used when the above formula is modified by rounding π (pi) down to 3 and cross canceling to get the formula:

$$V = 5L^3 \quad (24-2)$$

Thus, a single 10-ft driven rod will utilize 5000 cubic ft of soil and a single 8-ft rod will utilize about half the soil at 2560 cubic ft.

24.3 GROUNDING ELECTRODES

Grounding is the process of electrically connecting any metallic object to the earth by the way of an earth electrode system. The *NEC* requires that the grounding electrodes be tested to ensure that they are under 25- Ω RTG (earth).

It is important to know, that aluminum electrodes are not allowed for use in grounding (Table 24-1).

24.3.1 Driven Rod

The standard driven rod or copper-clad rod (Fig. 24-2) consists of an 8- to 10-ft length of steel with a 5- to 10-mil coating of copper. This is by far the most common grounding device used in the field today. The driven rod has been in use since the earliest days of electricity with a history dating as far back as Benjamin Franklin.

TABLE 24-1 Earth-Electrode Comparison Chart

	Driven rod	Advanced driven rod	Grounding plate	Concrete encased electrode	Building foundation	Water pipe	Electrolytic electrode
Resistance-to-ground (RTG)	Poor	Average	Poor	Average	Above average	Poor	Excellent
Corrosion resistance	Poor	Good	Poor	Good*	Good*	Varies	High
Increase in RTG in cold weather	Highly affected	Slightly affected	Highly affected	Slightly affected	Highly affected	Varies w/ contact to earth	Minimally affected
Increase in RTG over time	RTG worsens	RTG typically unaffected	RTG increases	RTG typically unaffected	RTG typically unaffected	RTG typically unaffected	RTG improves
Electrode ampacity	Poor	Average	Average	Average*	Above average*	Poor	Excellent
Installation cost	Average	Excellent	Below average	Below average	Average	Average	Poor
Life expectancy	Poor 5–10 years	Average 15–20 years	Poor 5–10 years	Average* 15–20 years	Above average* 20–30 years	Below average* 10–15 years	Excellent 30–50 years

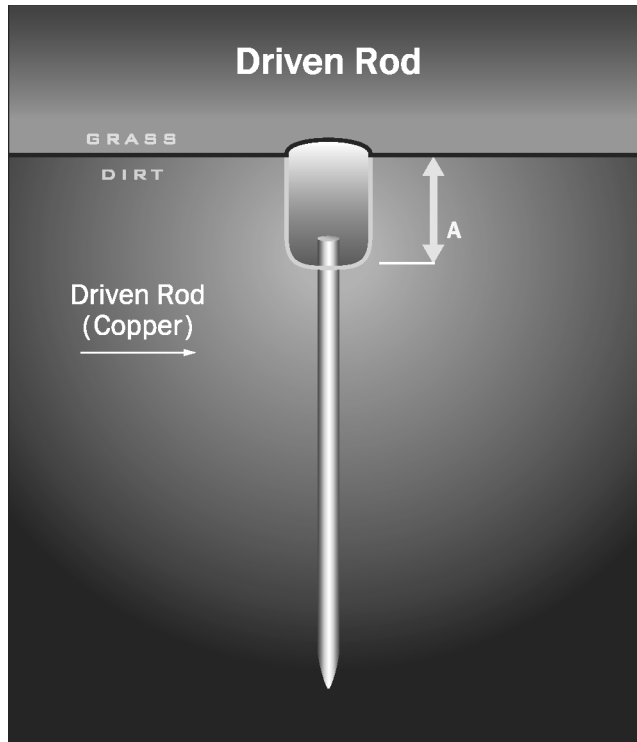


FIGURE 24-2 Copper-clad driven grounding rod.

Driven rods are relatively inexpensive to purchase, however, ease of installation is dependent upon the type of soil and terrain where the rod is to be installed. The steel used in the manufacture of a standard driven rod tends to be relatively soft. Mushrooming can occur on both the tip of the rod as it encounters rocks on its way down, and the end where force is being applied to drive the rod through the earth. Driving these rods can be extremely labor-intensive as rocky terrain creates problems as the tips of the rods continue to mushroom.

Often these rods will hit a rock and actually turn back around on themselves and pop back up a few feet away from the installation point. Because driven rods range in length from 8 to 10 ft, often a ladder is required to reach the top of the rod, which can become a safety issue. Many falls have occurred from personnel trying to literally “whack” these rods into the earth while hanging from a ladder many feet in the air.

The *NEC* requires that driven rods be a minimum of 8 ft in length and that 8 ft of length must be in direct contact with the soil. Typically, a shovel is used to dig down into the ground 18 in before a driven rod is installed. The most common rods used by commercial and industrial contractors are in 10-ft lengths. Many industrial specifications require this length as a minimum.

A common misconception is that the copper coating on a standard driven rod has been applied for electrical reasons. While copper is certainly a conductive material, its real purpose on the rod is to provide corrosion protection for the steel underneath. Many corrosion problems can occur because copper is not always the best choice in corrosion protection. It should be noted that galvanized driven rods have been developed to address the corrosion concerns that copper presents, and in many cases are a better choice for prolonging the life of the grounding rod and grounding systems. Generally speaking, galvanized rods are a better choice in all but high salt environments.

An additional drawback of the copper-clad driven rod is that copper and steel are two dissimilar metals. When an electrical current is imposed, electrolysis will occur. Additionally, the act of driving the rod into the soil can damage the copper cladding, allowing corrosive elements in the soil to attack the bared steel and further decrease the life expectancy of the rod. Environment, aging, temperature, and moisture also easily affect driven rods, giving them a typical life expectancy of 5 to 15 years in good soil conditions. Driven rods also have a very small surface area and that is not always conducive to good contact with the soil. This is especially true in rocky soil conditions where the rod will only make contact on the edges of the surrounding rock.

A good example of this is to imagine a driven rod surrounded by large marbles. Actual contact between the marbles and the driven rod will be very small. Because of this small surface contact with the surrounding soil, the RTG will increase, lowering the conductance, and limiting its ability to handle high-current faults.

24.3.2 Advanced Driven Rods

Advanced driven rods (Fig. 24-3) are specially engineered varieties of the standard driven rod with several key improvements. Because they present lower physical resistance, advanced rods can now be installed in terrain where only large drill rigs could install before and can quickly be installed in less demanding environments. The modular design of these rods can reduce safety-related accidents during installation. Larger surface areas can improve electrical conductance between the soil and the electrode.

Of particular interest is that advanced driven rods can easily be installed to depths of 20 ft or more depending upon soil conditions. Advanced driven rods are typically driven into the ground with a

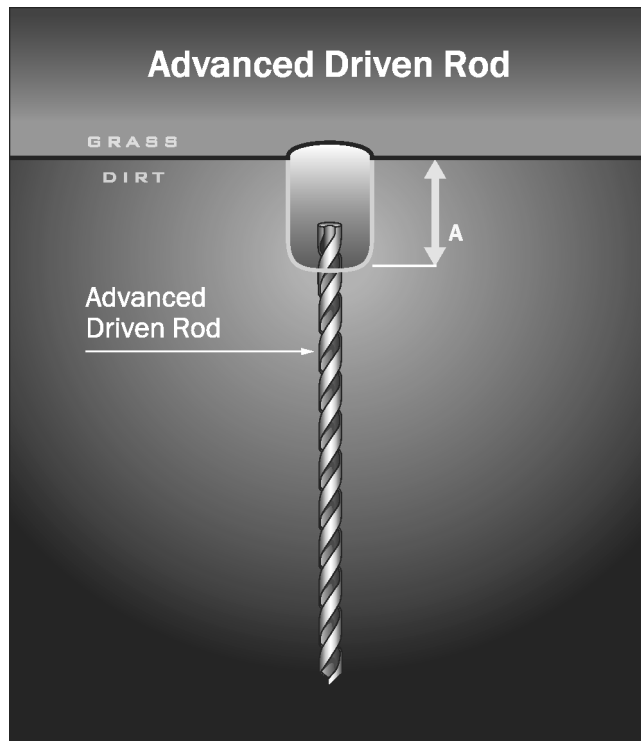


FIGURE 24-3 Advanced driven grounding rod.

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standard drill hammer. The tip of an advanced driven rod is typically made of carbide and works in a similar manner to a masonry drill bit, allowing the rod to bore through rock with relative ease. Advanced driven rods are modular in nature and are designed in 5 ft lengths. They have permanent and irreversible connections that enable them to be installed safely while standing on the ground. Typically, a shovel is used to dig down into the ground 18 in before the advanced driven rod is installed. The advanced driven rod falls into the same category as a driven rod and is applicable to the same codes and regulations.

In the extreme northern and southern climates of the planet, frost-heave is a major concern. As frost sets in every winter, unsecured objects buried in the earth tend to be pushed up and out of the ground. Driven grounding rods are particularly susceptible to this action. Anchor plates are often welded to the bottom of the rods to prevent them from being pushed up and out of the earth by frost-heave. This, however, requires that a hole be augured into the earth in order to get the anchor plate into the ground, which can dramatically increase installation costs. Advanced driven rods do not suffer from frost-heave issues and can be installed easily in extreme climates.

24.3.3 Grounding Plates

Grounding plates are typically thin copper plates buried in direct contact with the earth (Fig. 24-4). The *NEC* requires that ground plates have at least 2 ft² of surface area exposed to the surrounding soil. Ferrous materials must be at least 0.20 in thick, while nonferrous materials (copper) need only be 0.060 in thick. Grounding plates are typically placed under poles or supplementing counterpoises.

As shown in “A” on Fig. 24-4, grounding plates should be buried at least 30 in below grade level. While the surface area of grounding plates is greatly increased over that of a driven rod, the zone of influence is relatively small as shown in “B.” The *zone of influence* of a grounding plate can be as small as 17 in. This ultra-small zone of influence typically causes grounding plates to have a higher resistance reading than other electrodes of similar mass. Similar environmental conditions that lead to the failure of the driven rod also plague the grounding plate such as, corrosion, aging, temperature, and moisture.

24.3.4 Ufer Ground or Concrete Encased Electrodes

Originally, Ufer grounds were copper electrodes encased in the concrete surrounding ammunition bunkers. In today’s terminology, Ufer grounds consist of any concrete-encased electrode, such as the rebar in building foundations, wire or wire mesh when used for grounding.

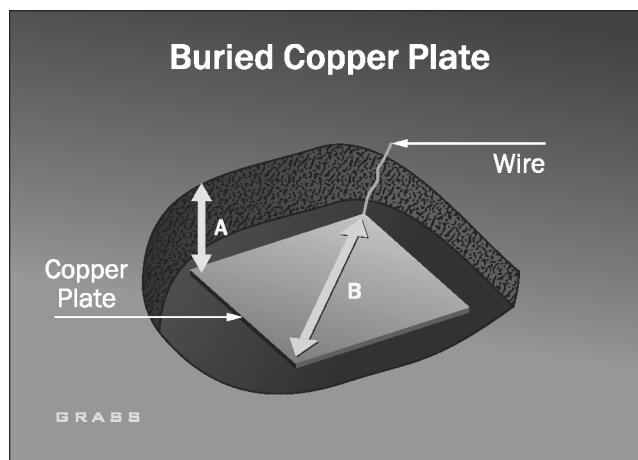


FIGURE 24-4 Buried copper plate.

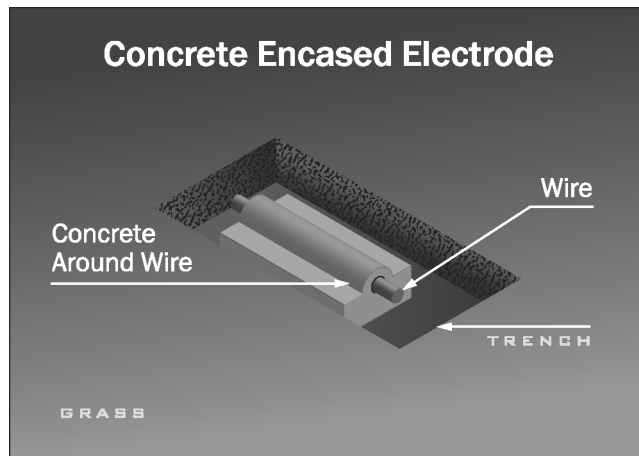


FIGURE 24-5 Concrete encased electrode.

Concrete Encased Electrode. The *NEC* requires that concrete-encased electrodes (Fig. 24-5) use a minimum no. 4 AWG copper wire at least 20 ft in length and encased in at least 2 in of concrete. The advantages of concrete encased electrodes are that they dramatically increase the surface area and amount of contact with the surrounding soil. However, the zone of influence is not increased; therefore, the resistance to ground is typically only slightly lower than the wire would be without the concrete.

Concrete encased electrodes also have some significant disadvantages. When an electrical fault occurs, the electric current must flow through the concrete into the earth. Concrete, by nature, retains a lot of water, which rises in temperature as the electricity flows through the concrete. If the extent of the electrode is not sufficiently great for the total current flowing, the boiling point of the water may be reached, resulting in an explosive conversion of water into steam. Many concrete-encased electrodes have been destroyed after being subjected to relatively small electrical faults. Once the concrete cracks apart and falls away from the conductor, the concrete pieces act as a shield preventing the copper wire from contacting the surrounding soil, resulting in the dramatic increase in the RTG of the electrode.

There are many new products available on the market designed to improve the concrete encased electrodes. The most common are modified concrete products that incorporate conductive materials into the cement mix and are usually carbon. The advantage of these products is that they are fairly effective in reducing the resistivity of the concrete, thus lowering the RTG of the electrode encased. The most significant improvement of these new products is in reducing heat buildup in the concrete during fault conditions, which can lower the chances that steam will destroy the concrete encased electrode.

However, some disadvantages are still evident. Again, these products do not increase the zone of influence and as such the RTG of the concrete encased electrode is only slightly better than what a bare copper wire or driven rod would be in the ground. Also a primary concern regarding enhanced grounding concretes is the use of carbon in the mix. Carbon and copper are of different nobilities and will sacrificially corrode each other over time. Many of these products claim to have buffer materials designed to reduce the accelerated corrosion of the copper caused by the addition of carbon into the mix. However, few independent long-term studies are being conducted to test these claims.

Ufer Ground or Building Foundations. Ufer grounds (Fig. 24-6) or building foundations may be used provided that the concrete is in direct contact with the earth (no plastic moisture barriers); that rebar is at least 0.500 in in diameter; and that there is a direct metallic connection from the service ground to the rebar buried inside the concrete.

This concept is based on the conductivity of the concrete and the large surface area. This will usually provide a grounding system that can handle very high current loads. The primary drawback

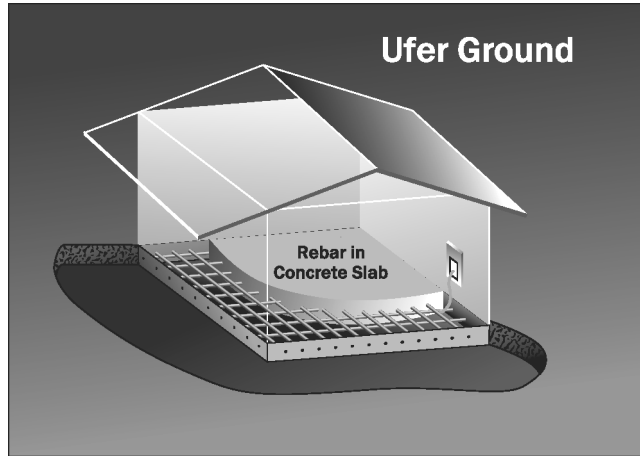


FIGURE 24-6 Building foundation or Ufer.

occurs during fault conditions. If the fault current is too great compared with the area of the rebar system when moisture in the concrete superheats and rapidly expands, cracking the surrounding concrete and threatening the integrity of the building foundation. Another drawback to the Ufer ground is that they are not testable under normal circumstances, as isolating the concrete slab in order to properly perform resistance-to-ground testing is nearly impossible.

The metal frame of a building may also be used as a grounding point, provided that the building foundation meets the above requirements and is commonly done in high-rise buildings. It should be noted that many owners of these high-rise buildings are banning this practice and insisting that tenants run ground wires all the way back to the secondary service locations on each floor. The owners will have already run ground wires from the secondary services back to the primary service locations and installed dedicated grounding systems at these service locations. The goal is to avoid the flow of stray currents that can interfere with the operation of sensitive electronic equipment.

24.3.5 Water Pipes

Water pipes have been used extensively in the past as a grounding electrode. Water pipe connections are not testable and are unreliable due to the use of tar coatings and plastic fittings. City water departments have begun to specifically install plastic insulators in the pipelines to prevent the flow of current and reduce the corrosive effects of electrolysis. Since water pipes are continuous city wide, fault conditions in adjacent neighborhoods could backfeed current into sensitive equipment causing unintentional damage. The *NEC* requires that at least one additional electrode be installed when using water pipes as an electrode. There are several additional requirements including:

- 10 ft of the water pipe is in direct contact with the earth
- Joints must be electrically continuous
- Water meters may not be relied upon for the grounding path
- Bonding jumpers must be used around any insulating joints, pipe, or meters
- Primary connection to the water pipe must be on the street side of the water meter
- Primary connection to the water pipe shall be within 5 ft of the point of entrance to the building

The *NEC* requires that water pipes be bonded to ground, even if water pipes are not used as part of the grounding system.

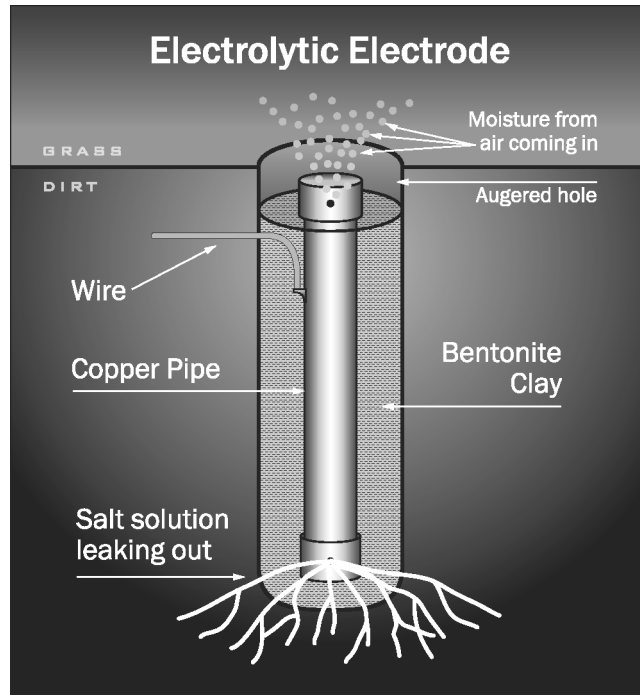


FIGURE 24-7 Electrolytic electrode.

24.3.6 Electrolytic Electrode

The electrolytic electrode (Fig. 24-7) was specifically engineered to eliminate the drawbacks found in other grounding electrodes. This active grounding electrode consists of a hollow copper shaft filled with natural earth salts and desiccants that have a hygroscopic nature to draw moisture from the air. The moisture mixes with the salts to form an electrolytic solution that continuously seeps into the surrounding backfill material, keeping it moist and high in ionic content.

The electrolytic electrode is installed into an augured hole and backfilled with a special highly conductive product. This specialty product should protect the electrode from corrosion and improve its conductivity. The electrolytic solution and the special backfill material work together to provide a solid connection between the electrode and the surrounding soil that is free from the effects of temperature, environment, and corrosion. This active electrode is the only grounding electrode that improves with age. All other electrode types will have a rapidly increasing RTG as the season's change and the years pass. The drawbacks to these electrodes are the cost of installation and the cost of the electrode itself.

24.4 SYSTEM DESIGN AND PLANNING

A grounding design starts with a site analysis, collection of geological data, and soil resistivity of the area. Typically the site engineer or equipment manufacturers specify a RTG number. The NEC states that the resistance-to-ground shall not exceed $25\ \Omega$ for a single electrode. However, high technology manufacturers will often specify 3 or $5\ \Omega$ depending upon the requirements of their equipment. For sensitive equipment and under extreme circumstances a one ohm specification may sometimes be required.

TABLE 24-2 Surface Materials vs. Resistivity

Type of surface material	Resistivity of sample in Ωm	
	Dry	Wet
Crusher granite w/fines	140×10^6	1,300
Crusher granite w/fines 1.5"	4,000	1,200
Washed granite—pea gravel	40×10^6	5,000
Washed granite 0.75"	2×10^6	10,000
Washed granite 1–2"	1.5×10^6 to 4.5×10^6	5,000
Washed granite 2–4"	2.6×10^6 to 3×10^6	10,000
Washed limestone	7×10^6	2,000 to 3,000
Asphalt	2×10^6 to 30×10^6	10,000 to 6×10^6
Concrete	1×10^6 to 1×10^9	21 to 100

When designing a ground system the difficulty and costs increase exponentially as the target RTG approaches the unobtainable goal of 0Ω .

24.4.1 Data Collection

Once a need is established, data collection begins. Soil resistivity testing, geological surveys, and test borings provide the basis for all grounding design. Proper soil resistivity testing using the Wenner 4-point method is recommended because of its accuracy. This method will be discussed later in this chapter. Additional data is always helpful and can be collected from the existing ground systems located at the site. For example, driven rods at the location can be tested using the 3-point fall-of-potential method or an induced frequency test using a clamp-on ground resistance meter.

24.4.2 Data Analysis

With all the available data, sophisticated computer programs can provide a soil model showing the resistivity in Ωms and at various layer depths. Knowing at what depth the most conductive soil is located for the site allows the design engineer to model a system to meet the needs of the application.

24.4.3 Grounding Design

Soil resistivity is the key factor that determines the resistance or performance of a grounding system. It is the starting point of any grounding design. As you can see in Figs. 24-10 and 24-11, soil resistivity varies dramatically throughout the world and is heavily influenced by electrolyte content, moisture, minerals, compactness, and temperature (Table 24-2).

24.5 SOIL RESISTANCE TESTING

Soil resistance testing or soil resistivity testing is the process of measuring a volume of soil to determine the conductivity of the soil. The resulting soil resistivity is expressed in Ωm or ohm-centimeter.

Soil Resistivity testing is the single most critical factor in electrical grounding design. This is true when discussing simple electrical design, to dedicated low-resistance grounding systems, or to the far more complex issues involved in GPR studies. Good soil models are the basis of all grounding designs and they are developed from accurate soil resistance testing.

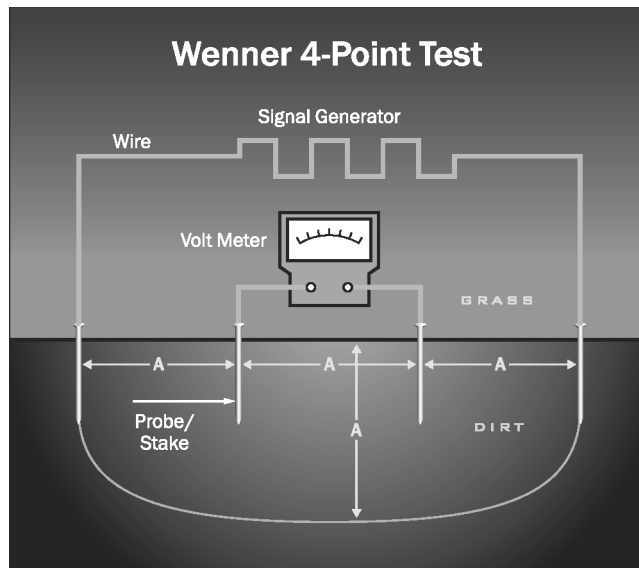


FIGURE 24-8 Wenner 4-point testing pattern.

24.5.1 Wenner Soil Resistivity Test or 4-point Test

The Wenner 4-point method (Fig. 24-8) is by far the most used test method to measure the resistivity of soil. Other methods do exist, such as the General & Schlumberger method, however, they are infrequently used and vary only slightly in how the probes are spaced when compared to the Wenner method.

Electrical resistivity is the measurement of resistance in a unit quantity of a given material. It is expressed in Ω ms and represents the resistance measured between two plates covering opposite sides of a 1 m cube. This test is commonly performed at raw land sites, during the design and planning of grounding systems specific to the tested site. The test spaces four probes at equal distances to approximate the depth of the soil to be tested.

Typical spacing will be 1, 1.5, 2, 3, 4.5, 7, 10 ft, etc., with each spacing increasing from the preceding one by a factor of approximately 1.5, up to maximum spacing that is commensurate with the 1 to 3 times the maximum diagonal dimension of the grounding system being designed, resulting in a maximum distance between the outer current electrodes of 3 to 9 times the maximum diagonal dimension of the future grounding system. This is one “traverse” or set of measurements, and is typically repeated, albeit with shorter maximum spacing, several times around the location at right angles and diagonally to each other to ensure accurate readings.

The basic premise of the test is that probes spaced at a 5-ft distance across the earth, will read 5 ft in depth. The same is true if you space the probes 40 ft across the earth, you a weighted average soil resistance down to 40 ft in depth and all points in between. This raw data is usually processed with computer software to determine the actual resistivity of the soil as a function of depth.

Conducting a Wenner 4-point (or four-pin) Test. Figure 24-9 shows how to take one “traverse” or set of measurements. As the 4-point indicates, the test consists of four pins that must be inserted into the earth. The outer two pins are called the current probes, C1 and C2. These are the probes that inject current into the earth. The inner two probes are the potential probes, P1 and P2. These are the probes that take the actual soil resistance measurement.

In this test, a probe C1 is driven into the earth at the corner of the area to be measured. Probes P1, P2, and C2 are driven at 5, 10, and 15 ft respectively from rod C1 in a straight line to measure

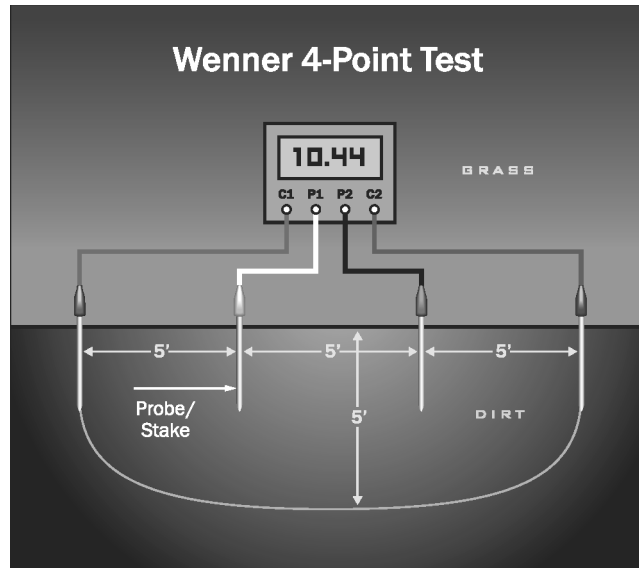


FIGURE 24-9 Wenner 4-point test setup.

the soil resistivity from 0 to 5 ft in depth. C1 and C2 are the outer probes and P1 and P2 are the inner probes. At this point, a known current is applied across probes C1 and C2, while the resulting voltage is measured across P1 and P2. Ohm's law can then be applied to calculate the measured resistance.

Probes C2, P1, and P2 can then be moved out to 10, 20, and 30 ft spacing to measure the resistance of the earth from 0 to 10 ft in depth. Continue moving the three probes (C2, P1, and P2) away from C1 at equal intervals to approximate the depth of the soil to be measured. Note that the performance of the electrode can be influenced by soil resistivities at depths that are considerably deeper than the depth of the electrode, particularly for extensive horizontal electrodes, such as water pipes, building foundations or grounding grids.

Soil Resistance Meters. There are basically two types of soil resistance meters: low- and high-frequency models. Both meter types can be used for 4-point and 3-point testing, and can even be used as standard (2-point) voltmeter for measuring common resistances.

Care should always be given when selecting a meter, as the electronics involved in signal filtering are highly specialized. Electrically speaking, the earth can be a noisy place. Overhead power lines, electric substations, railroad tracks, various signal transmitters, and many other sources contribute to signal noise found in any given location. Harmonics, 60 Hz background noise, and magnetic field coupling can confound the measurement signal resulting in apparent soil resistivity readings that are larger by an order of magnitude, particularly with large spacings. Selecting equipment with electronic packages capable of discriminating between these signals is critical.

High-Frequency meters typically operate at 128 pulses per second or other pulse rates except 60. These high-frequency meters typically suffer from the inability to generate sufficient voltage to handle long traverses and generally should not be used for probe spacings greater than 100 ft. Furthermore, the high-frequency signal flowing in the current lead induces a noise voltage in the potential leads, which cannot be completely filtered. This noise becomes greater than the measured signal as the soil resistivity decreases and the pin spacing increases. High-frequency meters are less expensive than their low-frequency counterparts and are by far the most common meter used in soil resistivity testing.

TABLE 24-3 Soil Types vs. Resistivity Chart

Soil types or type of earth	Average resistivity in Ωm
Bentonite	2 to 10
Clay	2 to 100
Wet organic soils	10 to 100
Moist organic soils	100 to 1,000
Dry organic soils	1,000
Sand and gravel	50 to 1,000
Surface limestone	100 to 10,000
Limestone	5 to 4,000
Shale's	5 to 100
Sandstone	20 to 2,000
Granites, basalts, etc.	1,000
Decomposed gneisses	50 to 500
Slates, etc.	10 to 100

Low-Frequency meters, which actually generate low frequency pulses (on the order of 0.5 to 2.0 seconds per pulse), are the preferred equipment for soil resistivity testing, as they do away with the induction problem from which the high-frequency meters suffer. However they can be very expensive to purchase. Depending upon the equipment's maximum voltage, low-frequency meters can take readings with extremely large probe spacings and often many thousands of feet in distance. Typically, the electronics filtering packages offered in low-frequency meters are superior to those found in high-frequency meters. Caution should be taken to select a reputable manufacturer.

Data Analysis. Once all the resistance data are collected, formula 24-3 can be applied to calculate the apparent soil resistivity in Ωms . For example, if an apparent resistance of 4.5Ω is at 40-ft spacing, the soil resistivity in Ωms would be 344.7. One refers to "apparent" resistivity, because this does not correspond to the actual resistivity of the soil. This raw data must be interpreted by suitable methods in order to determine the actual resistivity of the soil (Table 24-3).

**Soil Resistivity
4-Point Data Interpretation**

$$\rho = 1.915AR$$

$$\rho = 1.915(40)(4.5)$$

$$\rho = \frac{4\pi AR}{1 + \frac{2A}{\sqrt{(A^2 + 4B^2)} - \sqrt{(A^2 + B^2)}}}$$

ρ = Resistivity A = Spacing of Probes

B = Depth of Probes R = Resistance (reading from meter)

If $A > 20B$, then $\rho = 2\pi AR = 1.915 AR$

Shallow Depth Readings. Shallow depth readings, as little as 6 in deep are exceedingly important for most, if not all, grounding designs. The soil resistivity readings are actually weighted averages of the soil resistivity from the earth's surface down to the specified distance and include all the shallow

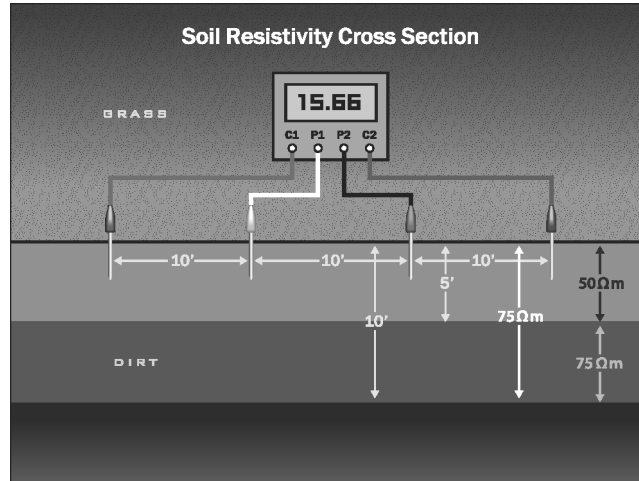


FIGURE 24-10 Importance of shallow readings.

resistance readings above it. The trick in developing the final soil model is to pull out the actual resistance of the soil at depth, and that requires subtracting the top layers from the deep readings.

Figure 24-10 demonstrates how the shallowest readings impact deeper ones below it. If the 5-ft reading shows 50- Ω m soil, and the 10-ft reading shows 75- Ω m soil, the actual soil resistance from 5 to 10 ft is 100- Ω m. The point here is to illustrate a concept that precomputed curves or computer software is needed to properly interpret the data. The same follows true for larger pin spacings. The shallowest readings are used over and over again in determining the actual resistance at depth.

Shallow-depth readings of 6 in, 1 ft, 1.5 ft, 2 ft, and 2.5 ft are important for grounding design. Because grounding conductors are typically buried at 1.5 to 2.5 ft below the surface of the earth. To accurately calculate how those conductors will perform at these depths, shallow soil readings must be taken. These shallow readings become even more important when engineers calculate GPR and step and touch voltages.

It is critical that the measurement probes and current probes be inserted into the earth to the proper depth for shallow soil resistivity readings. If the probes are driven too deep, then it can be difficult to resolve the resistivity of the shallow soil. A rule of thumb is that the penetration depth of the potential probes should be no more than 10% of the pin spacing, whereas the current probes must not be driven more than 30% of the pin spacing.

Deep Readings. Often, the type of meter used determines the maximum depth or spacing that can be read. A general guideline is that high-frequency soil resistivity meters are good for no more than 100-ft pin spacings, particularly in low resistivity soils. For greater pin spacings, low-frequency soil resistivity meters are required. They can generate the required voltage needed to push the signal through the soil at deep distances and detect a weak signal, free of induced voltage from the current injection leads.

24.5.2 Test Location

Soil resistivity testing should be conducted as close to the proposed grounding system as possible, taking into consideration the physical items that may cause erroneous readings. There are two issues that may cause poor quality readings:

1. Electrical interference causing unwanted signal noise to enter the meter.
2. Metallic objects “short-cutting” the electrical path from probe to probe. The rule of thumb here is that a clearance equal to the pin spacing should be maintained between the measurement traverse and any parallel buried metallic structures.

Testing in the vicinity of the site in question is obviously important; however, it is not always practical. Many electric utility companies have rules regarding how close the soil resistivity test must be in order to be valid. The geology of the area also plays into the equation as dramatically different soil conditions may exist only a short distance away.

When left with little room or poor conditions in which to conduct a proper soil resistivity test, one should use the closest available open field with as similar geological soil conditions as possible.

24.6 TESTING OF EXISTING GROUNDING SYSTEMS

The measurement of ground resistance for an earth electrode system is very important. It should be done when the electrode is first installed, and then at periodic intervals thereafter. This ensures that the RTG does not increase over time. There are two methods for testing an existing earth-electrode system. The first is the 3-point or fall-of-potential method and the second is the Induced Frequency test or clamp on method. The 3-point test requires complete isolation from the power utility. Not just power isolation, but also removal of any neutral or other such ground connections extending outside the grounding system. This test is the most suitable test for large grounding systems and is also suitable for small electrodes. The induced frequency test can be performed while power is on and actually requires the utility to be connected to the grounding system under test. This test is accurate only for small electrodes, as it uses frequencies in the kilohertz range, which see long conductors as inductive chokes and therefore do not reflect the 60 Hz resistance of the entire grounding system.

24.6.1 Fall-of-Potential Method or 3-point Test

The 3-point or fall-of-potential method (Fig. 24-11) is used to measure the RTG of existing grounding systems. The two primary requirements to successfully complete this test are the ability to isolate the grounding system from the utility neutral and knowledge of the diagonal length of the grounding system (i.e., a 10-ft $\times$ 10-ft grounding ring would have a 14 ft diagonal length). In this test, a short probe, referred to as probe Z, is driven into the earth at a distance of 10 times (10 $\times$) the

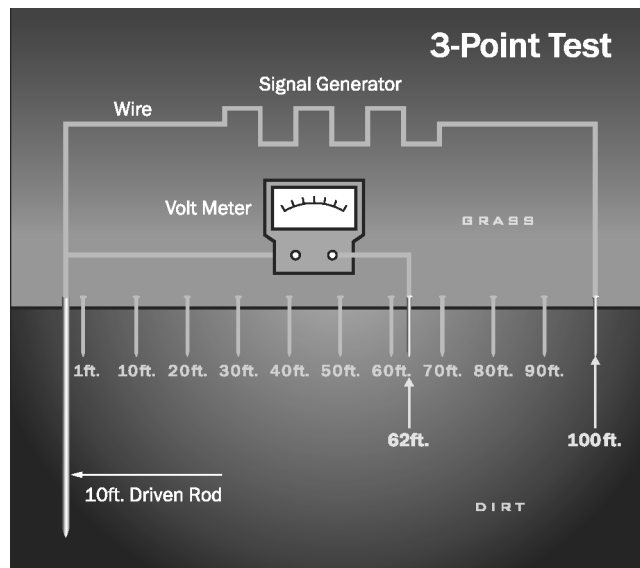


FIGURE 24-11 3-point test method.

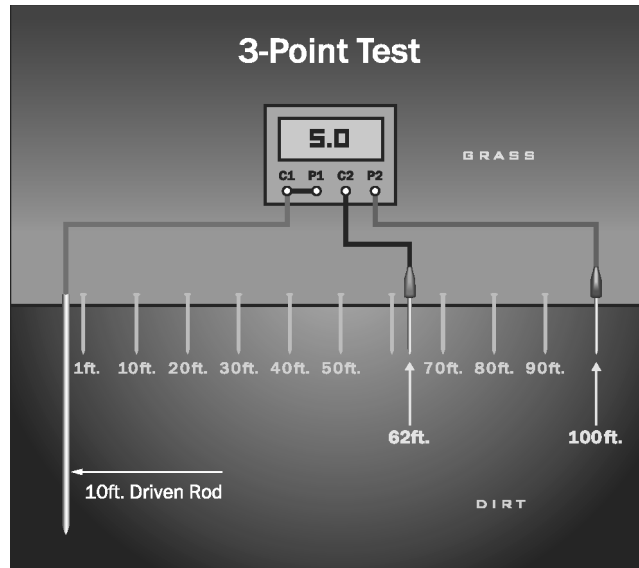


FIGURE 24-12 3-point test setup.

diagonal length of the grounding system (rod X). A second probe (Y) is placed in-line at a distance from rod X equal to the diagonal length of the grounding system.

At this point, a known current is applied across X and Z, while the resulting voltage is measured across X and Y. Ohm's Law can then be applied ($R = V/I$) to calculate the measured resistance. Probe Y is then moved out to a distance of 2x the diagonal length of the grounding system, in-line with X and Z, to repeat the resistance measurement at the new interval. This will continue, moving probe Y out to 3x, 4x, ... 9x the diagonal length to complete the 3-point test (Fig. 24-12) with a total of nine resistance measurements.

Graphing & Evaluation. The 3-point test is evaluated by plotting the results as data points with the distance from rod X along the x-axis and the resistance measurements along the y-axis to develop a curve. Roughly midway between the center of the electrode under test and the probe Z, a plateau or "flat spot" should be found, as shown in the graph. The resistance of this plateau (actually, the resistance measured at the location 62% from the center of the electrode under test, if the soil is perfectly homogeneous) is the RTG of the tested grounding system.

Invalid Tests. If no semblance of a plateau is found and the graph is observed to rise steadily, the test is considered invalid (Fig. 24-13). This can be due to the fact that probe Z was not placed far enough away from rod X, and can usually indicate that the diagonal length of the grounding system was not determined correctly. If the graph is observed to have a low plateau that extends the entire length and only rises at the last test point, then this also may be also considered invalid. This is because the utility or telecom neutral connection remains on the grounding system.

24.6.2 Induced Frequency Testing or Clamp-On Testing

The induced frequency testing (Fig. 24-14) or commonly called the "clamp-on" test is one of the newest test methods for measuring the RTG of a grounding system or electrode. This test uses a special transformer to induce an oscillating voltage (often 1.7 kHz) into the grounding system. Unlike the 3-point test which requires the grounding system to be completely disconnected and isolated

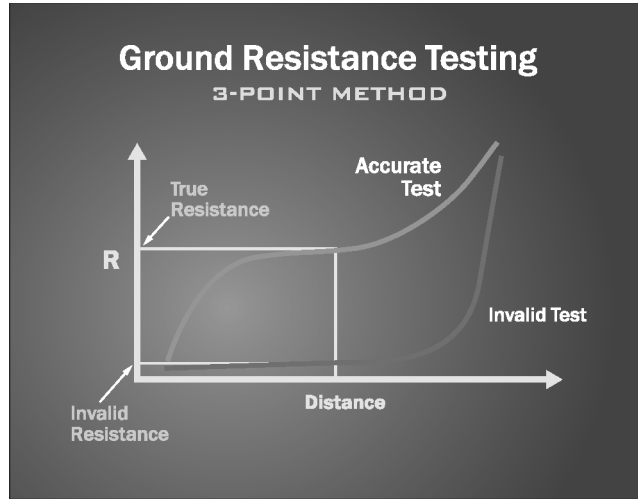


FIGURE 24-13 Comparison of valid vs. invalid 3-point test.

before testing, this method requires that the grounding system under test be connected to the electric utilities (or other large grounding system such as from the telephone company) grounding system (typically via the neutral return wire) to provide the return path for the signal. This test is the only test that can be used on “live” or “hot” systems. However, there are some limitations, including:

1. The amount of current running through the tested system must be below the equipment manufacturers limits.
2. The test signal must be injected at the proper location, so that the signal is forced through the grounding system and into the earth.
3. This instrument actually measures the sum of the resistance of the grounding system under test and the impedance of the utility neutral grounding, including the neutral wiring. Due to the high frequency used, the impedance of the neutral wiring is nonnegligible and can be greater than the

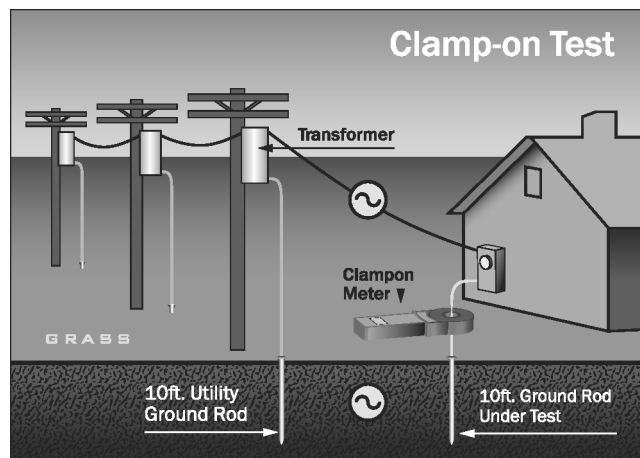


FIGURE 24-14 Induced frequency test diagram.

ground resistance of a very low resistance grounding system, which can therefore not be measured accurately.

4. The ground resistance of a large grounding system at 60 Hz can be significantly lower than at 1.7 kHz.

Many erroneous tests have been conducted where the technician only measured metallic loops and not the true RTG of the grounding system. The veracity of the induced frequency test has been questioned due to testing errors; however, when properly applied to a small to medium sized, self-standing grounding system, this test is rapid and reasonably accurate.

Test Application. The proper use of this test method requires the utility neutral to be connected to a wye-connected transformer. The oscillating voltage is induced into the grounding system at a point where it will be forced into the soil and return through the utility neutral. Extreme caution must be taken at this point as erroneous readings and mistakes are often made. The most common of these occur when clamping on or inducing the oscillating voltage into the grounding system at a point where a continuous metallic path exists back to the point of the test. This can result in a continuity test being performed rather than a ground resistance test. Understanding the proper field application of this test is vital to obtaining accurate results. The induced frequency test can test grounding systems that are in use and does not require the interruption of service to take measurements.

Ground Resistance Monitoring. Ground resistance monitoring is the process of automated timed and/or continuous RTG measurement. These dedicated systems use the induced frequency test method to continuously monitor the performance of critical grounding systems. Some models may also provide automated data reporting. These new meters can measure RTG and the current that flows on the grounding systems that are in use. Another benefit is that it does not require interruption of the electrical service to take these measurements.

24.7 GROUND POTENTIAL RISE

Ground potential rise is a phenomenon that occurs when large amounts of electricity enter the earth. This is typically caused when substations or high-voltage towers fault, or when lightning strikes occur (fault current). When currents of large magnitude enter the earth from a grounding system, not only will the grounding system rise in electrical potential, but so will the surrounding soil as well (Fig. 24-15).

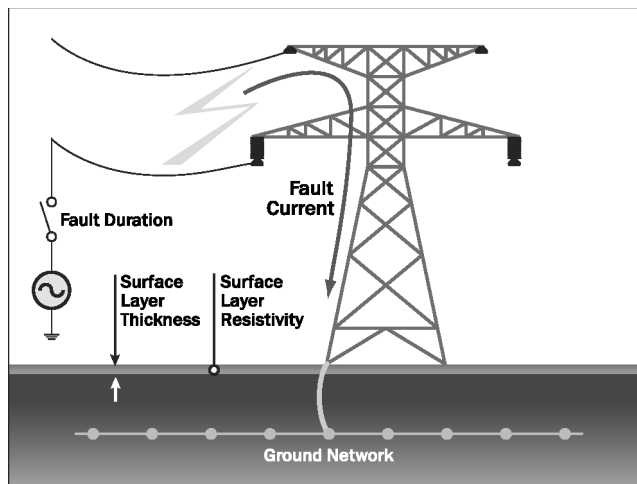


FIGURE 24-15 Electric fault at a transmission tower.

The voltages produced by a GPR event can be hazardous to both personnel and equipment. As described earlier, soil has resistance which will allow an electrical potential gradient or voltage drop to occur along the path of the fault current in the soil. The resulting potential differences will cause currents to flow into any and all nearby grounded conductive bodies, including concrete, pipes, copper wires, and people.

Ground Potential Rise Definitions. GPR as defined in IEEE Std. 367 is the product of a ground electrode impedance, referenced to remote earth, and the current that flows through that electrode impedance.

GPR as defined by IEEE Std. 80-2000 as the maximum electrical potential a substation grounding grid may attain, relative to a distant grounding point assumed to be at the remote earth potential. This voltage, GPR, is equal to the maximum grid current times the grid resistance.

Ground Potential Rise events are a concern wherever electrical currents of large magnitude flow into the earth. This can be at a substation, high-voltage tower or pole, or a large transformer. In cases where a GPR event may be of special concern, grounding precautions are required to ensure personnel and equipment safety.

Electrical potentials in the earth drop abruptly around the perimeter of a grounding system, but do not drop to zero. In fact, in a perfectly homogeneous soil, soil potentials are inversely proportional to the distance from the center of the grounding system, once one has reached a distance that is a small number of grounding system dimensions away. The formula is as follows:

$$\text{Earth potential} = \text{soil resistivity} \times \text{current} / (2 \times \pi \times \text{distance})$$

Where earth potential is in volts, soil resistivity is in Ωms , current is the current flowing into the soil from the grounding system, in amperes, π is 3.14159 ... and distance is in meters. Probably the most commonly noted GPR event involves the death of cows in a field during a lightning strike. Imagine lightning striking the center of an open field where cows are standing. The current injected into the earth flows radially away from the strike point, in all directions, creating voltage gradients on the surface of the earth, also in a radial direction. All the cows facing the lightning strike would have their fore hooves closer to the strike point than their rear hooves. This would result in a difference of potential between their fore and rear legs, causing current to flow through their bodies, including the heart area, and killing the cow. On the other hand, those cows with their flanks turned towards the lightning strike would have a greater chance of surviving, as the distance between their fore legs and therefore the voltage applied between them, would be relatively small, resulting in a lesser current flow.

GPR studies are typically conducted on substations and high-voltage towers. Substations have relatively large grounding areas, especially when compared to high-voltage towers and poles. Towers and poles represent by far the most potentially dangerous and difficult GPR situations to handle and are often not protected, unless they are located in high exposure areas or have equipment installed at ground level at which service personnel might be required to work.

24.7.1 Ground Potential Rise Analysis

The primary purpose of a GPR study is to determine the level of hazard associated with a given high-voltage location for personnel and/or equipment. When the degree of hazard is identified the appropriate precautions must be made to make the site safe. To do this, the engineer must identify what the minimum grounding system for each location will be. The engineer must also take into consideration all local and federal guidelines including utility companies and other requirements.

For example, many utility companies require at a minimum that a simple ground ring be installed at least 18 in below ground and 3-ft from the perimeter of all metal objects. This ground ring is also referred to as a counterpoise.

Once the minimum grounding system is identified, the engineer can run a GPR analysis and identify the extent of any electrical hazards.

Typically items reported in a GPR study will include the following: The square footage and size of the proposed grounding grid, RTG of the proposed grounding system, the estimated fault current that would be seen at the site, voltage rise of the GPR (in volts) at the site, 300-V_{peak} line, the X/R ratio, and the fault clearing time in seconds. Touch and step voltages are usually computed as well, as these are the primary indicators of safety.

The grounding engineer needs three pieces of information to properly conduct a GPR Study:

1. Soil resistivity data
2. Site drawings with the proposed construction
3. Electrical data from the utility company

Soil Resistivity Data. The soil resistivity data should include apparent resistivity readings at pin spacings ranging from 0.5 or 1 ft to as many as three grounding grid diagonals, if practical. Touch and step voltages represent the primary concern for personnel safety. Understanding the characteristics of the soil at depths ranging from immediately underfoot to one or more grid dimensions is required for a cost-effective and safe grounding system to be designed.

Site Drawings. The proposed site drawings should show the layout of the high-voltage tower or substation, and any additional construction for new equipment that may be occurring on the site, including fencing and gate radius. Incoming power and telco runs should also be included. In the case of high-voltage towers, the height and spacing of the conductors carried on the tower, and any overhead ground wires that may be installed on the tower, need to be detailed during the survey. This information is needed to properly address all the touch and step voltage concerns that may occur on the site.

Electric Utility Data. The electric utility company needs to provide electrical data regarding the tower or substation under consideration. This data should include the name of the substation or the number of the tower, the voltage level, the subtransient X/R ratio, and the clearing times. In the case of towers, the line names of the substations involved, the amount of current contributed by each substation in the event of a fault, and the type and positions of the overhead ground wires, if any, with respect to the phase conductors installed on each tower or pole. If overhead ground wires are present, tower or pole ground resistances along the line are of interest as well, be they measured, average or design values.

This information is important, as high-voltage towers have small ground area, yet handle very large amounts of electricity. Knowing if a tower has an overhead ground wire is important, because the overhead wire will carry away a percentage of the current, which will depend on the overhead ground wire type and ground resistances of adjacent towers, to other towers in the run, reducing the GPR event. Additionally, towers with overhead ground wires tend to have shorter clearing times. The same holds for substations—overhead ground wires on transmission lines and neutral wires on distribution lines can significantly reduce the magnitude of fault current that flows into the substation grounding system during fault conditions.

The following information is required from the utility company:

1. Phase-to-ground fault current contributed by each power line circuit
2. Fault clearing time
3. Line voltage
4. Subtransient X/R ratio
5. The make/type/number of overhead ground wires on each tower/pole line and position with respect to the phase conductors
6. Ground wire continuity and bonding configuration back to the tower and substation

7. The average distance from tower-to-tower and tower-to-substation
8. Typical tower/pole ground resistance: measured or design values

As-built drawings are often acquired and are useful for towers with existing grounding systems. They are also useful in the case of modifications and upgrades to existing substations, which will have extensive grounding systems already installed.

24.7.2 Personnel Safety during Ground Potential Rise Events

The grounding engineer will be required to develop safety systems to protect any personnel working where GPR hazards are known to exist. Federal law mandates that all known hazards must be eliminated from the work place for the safety of workers. It is the engineer's choice on which voluntary standards to apply in order to comply with the law. Federal law 29 CFR 1910.269 specifically states that step and touch potentials must be eliminated on transmission and distribution lines that include any related communication equipment.

Substations are always considered workplaces and step and touch potentials must be eliminated. Transmission and distribution towers or poles are not always considered work places and therefore are often exempt from these requirements. Take, for example, a lonely tower on a mountain side or in the middle of the desert—these towers are not typically considered workplaces. However, any high-voltage tower or pole becomes a workplace as soon as equipment is installed that is not related to the electric utility company and requires outside vendors to support the new equipment. Cellular telecommunications, environmental monitoring, and microwave relay equipment are good examples of equipment that, when installed on a high-voltage tower, turns the tower into a workplace. This would make the elimination of step and touch potentials required.

Hazardous Voltages. Fibrillation current is the amount of electricity needed to cause cardiac arrest, from which recovery will not spontaneously occur, in a person and is a value based on statistics. IEEE Std. 80-2000 provides a method to determine the pertinent value of fibrillation current for a safety study, along with a good explanation of how it is derived. Many different methods exist for calculating fibrillation current; however the 50kg-IEEE method is the most commonly used in North America. The formula used shows that the fibrillation current level is inversely proportional to the square root of the fault duration; however, it must be increased by a correction factor, based on the subtransient X/R ratio, which can be quite large for shorter fault durations. If personnel working at a site during fault conditions experience voltages that will cause a current less than the fibrillation current to flow in their bodies, then they are considered safe. If a worker will experience a greater voltage than is acceptable, additional safety precautions must be taken.

The subtransient X/R ratio at the site of the fault is important in calculating the acceptable fibrillation current and to determine the maximum allowable step and touch voltages that can occur at any given site.

Fault duration is a very necessary piece of data for properly calculating step and touch potentials. The fault duration is the amount of time required for the power company to shut off the current in the event of a fault.

Ultimately the engineer must determine two things:

1. The site-specific maximum allowable voltage that a person can safely withstand
2. The actual voltages that will be experienced at the site during a fault

Each site will have different levels of voltages for both of the above. Unfortunately, we cannot simply say that a human being can withstand X -level of voltages and use that value all the time, since this voltage is determined by the surface layer resistivity, the fault duration and the subtransient X/R ratio. Additionally as each site has different fault durations and different soil conditions, it is critical that calculations be made for each and every possible fault location.

Step Potential. When a fault occurs at a tower or substation, the current will enter the earth. Based on the distribution of varying resistivity in the soil (typically, a horizontally layered soil is assumed) a corresponding voltage distribution will occur. The voltage drop in the soil surrounding the grounding system can present hazards for personnel standing in the vicinity of the grounding system. Personnel “stepping” in the direction of the voltage gradient could be subjected to hazardous voltages.

In the case of step potentials, electricity will flow if a difference in potential exists between the two legs of a person (Fig. 24-16). Calculations must be performed that determine how great the tolerable step potentials are and then compare those results to the step voltages expected to occur at the site.

Hazardous step potentials can occur a significant distance away from any given site. The more current that is pumped into the ground, the greater the hazard. Soil resistivity and layering plays a major role in how hazardous a fault occurring on a specific site may be. High soil resistivities tend to increase step potentials. A high resistivity top layer and low resistivity bottom layer tends to result in the highest step voltages close to the ground electrode; the low resistivity bottom layer draws more current out of the electrode through the high resistivity layer, resulting in large voltage drops near the electrode. Further from the ground electrode, the worst case scenario occurs when the soil has conductive top layers and resistive bottom layers; in this case, the fault current remains in the conductive top layer for much greater distances away from the electrode.

Fault clearing time is an important factor to consider as well. The more time it takes the electric utility company to clear the fault, the more likely it is for a given level of current to cause the human heart to fibrillate.

An important note to remember is that most power companies use automated reclosers. In the event of a fault, the power is shut off and then automatically turned back on. This is done in case the faults occurred due to an unfortunate bird that made a poor choice in where to rest, or dust that may have been burned off during the original fault. A few engineers believe that fibrillation current for step potentials must be far greater than touch potentials, as current will not pass through any vital organs in the former case. This is not always true as personnel that receive a shock due to step potentials may fall to the ground, only to be hit again, before they can get up, when the automatic reclosers activate.

Touch Potentials. When a fault occurs at a tower or substation the current will pass through any metallic object and enter the earth. Those personnel “touching” an object in the vicinity of the GPR

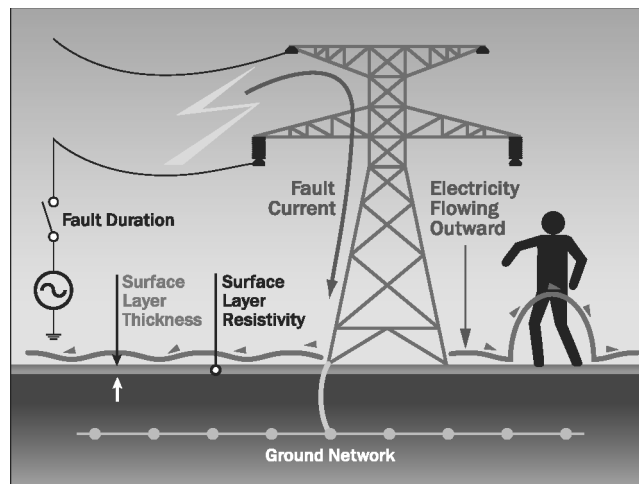


FIGURE 24-16 Step potential at a transmission tower.

will be subjected to these voltages which may be hazardous. For example if a person happens to be touching a high-voltage tower leg when a fault occurs, the current would travel down the tower leg into the persons hand and through vital organs of the body (Fig. 24-17). It would then continue on its path and exit out through the feet and into the earth. Careful analysis is required to determine the acceptable fibrillation currents that can be withstood by the body if a fault were to occur.

Engineering standards use a 1-m (3.28 ft) reach distance for calculating touch potentials. A 2-m (6.54 ft) reach distance is used when two or more objects are inside the GPR event area. For example, a person could be outstretching both arms and touching two objects at once such as a tower leg and a metal cabinet. Occasionally, engineers will use a 3-m distance to be particularly cautious, as they assume someone may be using a power tool with a power cord 3 m in length.

The selection of where to place the reference points used in the touch potential calculations are critical in getting an accurate understanding of the level of hazard at a given site. The actual calculation of touch potentials uses a specified object (such as a tower leg) as the first reference point. This means that the further away from the tower the other reference point is located, the greater the difference in potential. If you can imagine a person with incredibly long arms touching the tower leg and yet standing many dozens of feet away, you would have a huge difference in potential between the feet and the tower. Obviously, this example is not possible—this is why setting where and how far away the reference points used in the touch calculation is so important and why the 1-m rule has been established.

Mitigating Step and Touch Potential Hazards. Mitigating step and touch potential hazards is usually accomplished through one or more of the following three main techniques:

1. Reduction in the RTG of the grounding system
2. Proper placement of ground conductors
3. The addition of resistive surface layers

Understanding the proper application of these techniques is the key to reducing and eliminating any GPR hazards. Only through the use of highly sophisticated three-dimensional electrical simulation software that can model soil structures with multiple layers and finite volumes of different materials, can the engineer accurately model and design a grounding system that will safely handle high-voltage electrical faults.

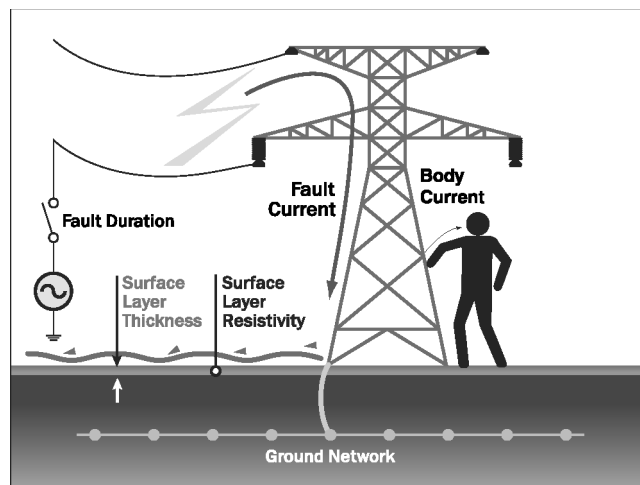


FIGURE 24-17 Touch potential at a transmission tower.

Reduce the Resistance-to-Ground. Reducing the RTG of the site is often the best way to reduce the negative effects of any GPR event, where practical. The GPR is the product of the fault current flowing into the grounding system times the RTG of the grounding system. Thus, reducing the RTG will reduce the GPR to the degree that the fault current flowing into the grounding system does increase in response to the reduced RTG. For example, if the fault current for a high-voltage tower is 5000 A and the RTG of the grounding system is 10- Ω , the GPR will be 50,000 V. If we reduce the RTG of the grounding system down to 5- Ω and the fault current increases to 7000 A as a result, then the GPR will become 35,000 V.

As seen in the example above, the reduction of the RTG can have the effect of allowing more current to flow into the earth at the site of the fault, but will always result in lower GPR values and touch and step voltages at the fault location. On the other hand, further away from the fault location, at adjacent facilities not connected to the faulted structure, the increase in current into the earth will result in greater current flow near these adjacent facilities and therefore an increase in the ground potential rise, touch voltages and step voltages at these facilities. Of course, if these are low to begin with, an increase may not represent a problem, but there are cases in which a concern may exist. Reducing the RTG can be achieved by any number of means as discussed earlier in this chapter.

Proper Placement of Ground Conductors. A typical specification for ground conductors at high-voltage towers or substations is to install a ground loop around all metallic objects, connected to the objects; keep in mind that it may be necessary to vary the depth and/or distance that ground loops are buried from the structure in order to provide the necessary protection. Typically these ground loops require a minimum size of 2/0 AWG bare copper conductor buried in direct contact with the earth and 3-ft from the perimeter of the object, 18 in below grade. The purpose of the loop is to minimize the voltage between the object and the earth surface where a person might be standing while touching the object—that is, to minimize touch potentials.

It is important that all metallic objects in a GPR environment be bonded to the ground system to eliminate any difference in potentials. It is also important that the resistivity of the soil as a function of depth be considered in computed touch and step voltages and in determining at what depth to place conductors. For example, in a soil with a dry, high-resistivity surface layer, conductors in this layer will be ineffective; a low resistivity layer beneath that one would be the best location for grounding conductors. On the other hand, if another high resistivity layer exists further down, long ground rods or deep wells extending into this layer will be ineffectual.

It is sometimes believed that placing horizontal grounding loop conductors very close to the surface results in the greatest reduction in touch potentials. This is not necessarily so, as conductors close to the surface are likely to be in drier soil, with a higher resistivity, thus reducing the effectiveness of these conductors. Furthermore, while touch potentials immediately over the loop may be reduced, touch potentials a short distance away may actually increase due to the decreased zone of influence of these conductors. Finally, step potentials are likely to increase at these locations; indeed, step potentials can be a concern near conductors that are close to the surface, particularly at the perimeter of a grounding system. It is common to see perimeter conductors around small grounding systems buried to a depth of 3-ft below grade, in order to address this problem.

Resistive Surface Layers. One of the simplest methods of reducing step and touch potential hazards is to wear electric hazard shoes. When dry, properly rated electric hazard shoes have millions of ohms of resistance in the soles and are an excellent tool for personnel safety. On the other hand, when these boots are wet and dirty, current may bypass the soles of the boots in the film of material that has accumulated on the sides of the boot. A wet leather boot can have a resistance on the order of 100 Ω . Furthermore, it cannot be assumed that the general public, who may have access to the outside perimeter of some sites, will wear such protective gear.

Another technique used in mitigating step and touch potential hazards is the addition of more resistive surface layers. Often a layer of crushed rock is added to a tower or substation to provide a layer of insulation between personnel and the earth. This layer reduces the amount of current that can flow through a given person and into the earth. Weed control is another important factor, as plants become energized during a fault and can conduct hazardous voltages into a person. Asphalt is an excellent alternative, as it is far more resistive than crushed rock, and weed growth is not a problem. The addition of resistive surface layers always improves personnel safety during a GPR event.

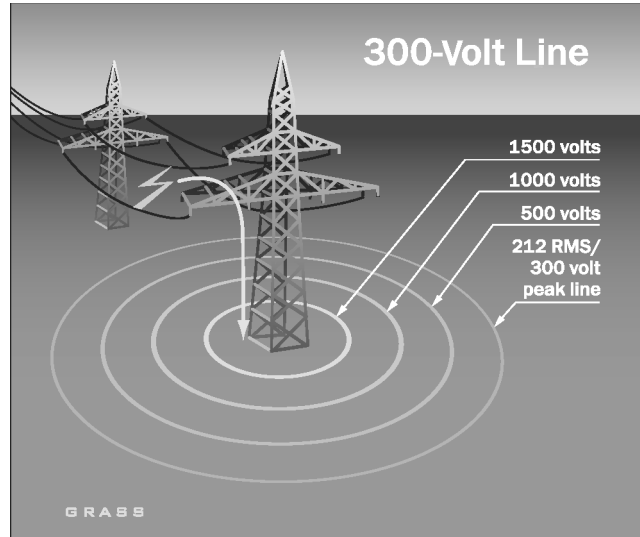


FIGURE 24-18 300-V line at a transmission tower.

Telecommunications in High-Voltage Environments. When telecommunications lines are needed at a high-voltage site, special precautions are required to protect switching stations from unwanted voltages. Installing wires in a substation or on a tower could present a hazardous situation and therefore certain precautions are required.

Industry standards regarding these precautions and protective requirements are covered in IEEE Standard's 387, 487, and 1590. These standards require that a GPR study be conducted so that the 300-V peak line can be properly calculated.

To protect the telephone switching stations, telecommunication standards require that fiber-optic cables be used instead of copper wires. A copper-to-fiber conversion box must be located outside the GPR event area at a distance in excess of the 300-V peak or 212-V RMS line (Fig. 24-18). This is known in the industry as the "300-V line." This means that based on the calculation results, copper wire from the telecommunications company may not come any closer than the 300-V peak distance. This is the distance where copper wire must be converted to fiber-optic cable. This can help prevent any unwanted voltages from entering the phone companies' telecommunications network.

The current formulae for calculating the 300-volt line, as listed in the standards, has led to misinterpretation and divergences of opinion, resulting in order-of-magnitude variations in calculated distances for virtually identical design input data. Furthermore, operating experience has shown that a rigorous application of theory results in unnecessarily large distances. This has caused many compromises within the telecommunications industry. The most noted one is a newer standard, IEEE Std. 1590-2003, that lists a 150-m (~500-ft) mark as a default distance, if a GPR study has not been conducted at a given location.

24.8 ACKNOWLEDGEMENT

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